

A cross-correlation of WMAP and ROSAT

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Abstract

We cross-correlate the recent CMB WMAP 1 year data with the diffuse soft X-ray background map of ROSAT. We look for common signatures due to galaxy clusters (SZ effect in CMB, bremsstrahlung in X-rays) by cross-correlating the two maps in real and in Fourier space. We do not find any significant correlation and we explore the different reasons for this lack of correlation. The most likely candidates are the possibility that we live in a low σ_8 universe ($\sigma_8 < 0.9$) and/or systematic effects in the data especially in the diffuse X-ray maps which may suffer from significant cluster signal subtraction during the point source removal process.

Key words: Galaxy clusters, CMB, X-rays

1 Introduction

The recent release of the WMAP data (Bennett et al. 2003) has opened a new window for studies of large-scale structure based on the well known Sunyaev-Zel'dovich effect (SZ effect) (Sunyaev & Zel'dovich, 1972). The SZ effect shifts the spectrum of the CMB photons to higher frequencies. This shift is redshift-independent and proportional to the product of the electron column density with the *average* temperature along the line of sight. The electron temperature and optical depth due to Thomson scattering are particularly high inside galaxy clusters. Thus, the SZ effect is a good tracer of clusters, even for those at high redshift. Around galaxy clusters, a diffuse, possibly filamentary, distribution of hot gas is believed to be present. These filaments have not been definitively detected due to their low contrast compared with the background

(either CMB or X-ray backgrounds). The same electrons which cause the SZ effect will also emit X-rays by bremsstrahlung emission. Therefore, one expects the SZ effect and the X-ray emission of galaxy clusters and filaments to be spatially correlated. Since the X-ray background and the CMB are not correlated (except at very large scales where there could be a correlation due to the integrated Sachs-Wolfe effect (Boughn et al. 1998)), the cross-correlation of an X-ray map with the CMB should enhance the signal of clusters and filaments with respect to the background. This fact motivates the present study.

We will be interested in studying the cross-correlation $SZ \otimes XR$ (where \otimes stands for cross-correlation). We need to define a *statistical object* to quantify this correlation. We will use the power spectrum of the $SZ \otimes XR$ map as such an object. We will also use the so-called cross-power spectrum (cross-correlation of the Fourier modes). There are several advantages to using the power spectrum and cross-power spectrum over other statistical objects. First, they contain useful information at different scales. For instance the 0 mode accounts for the correlation coefficient of the two maps. Higher modes will contain information about the fluctuations at smaller scales. The modelling of the power spectrum is also easier and it can easily account for the uncertainties in the assumptions made in the model. The power spectrum will also tell us something about the contribution of clusters and filaments to the CMB power spectrum. Previous papers have claimed an excess in the CMB power spectrum (Mason et al. 2003; Bond et al. 2002). It is not yet clear whether this excess could be caused by the SZ effect signal or just be inadequately subtracted residuals (compact sources or residual noise). An independent estimation of the SZ effect power spectrum would help to clarify this point. The reader can find all the details of this work on Diego et al. (2003)

2 The cross-correlation WMAP \otimes ROSAT

WMAP data consists of 5 all-sky maps at five different frequencies ($23 \text{ GHz} < \nu < 94 \text{ GHz}$). At low frequencies, these maps show strong galactic emission (synchrotron and free-free). The highest frequency maps (41-94 GHz) are the cleanest in terms of galactic contaminants and will be the most interesting for our purpose. We will focus on one basic linear combination of the WMAP data, the differenced $Q - W$ bands of the 1° smoothed version of the original data. This differencing completely removes the main contaminant in this work, the CMB, leaving a residual dominated by galactic and extragalactic foregrounds as well as filtered instrumental noise.

On the other hand, the ROSAT All-Sky Survey data (RASS, see Snowden et al. 1997) is presented in a set of bands ($\approx 0.1 - 2 \text{ keV}$). Low energy bands are highly contaminated by local emission (local bubble and Milky Way galaxy)

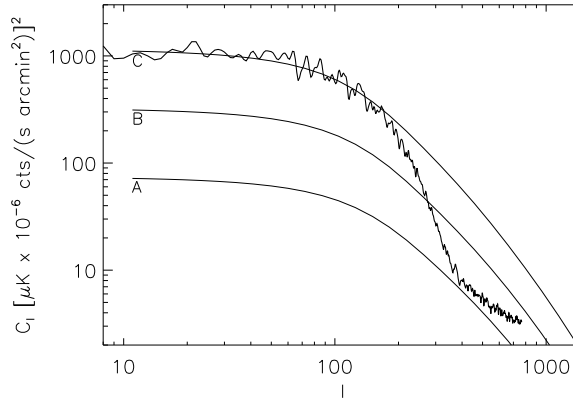


Fig. 1. Power spectrum of (Q-W)WMAP times ROSAT-R6. The thin solid lines are the predicted signals for models with $\sigma_8 = 0.8$ (A), $\sigma_8 = 0.9$ (B) and $\sigma_8 = 1.0$ (C).

while high energy bands show an important contribution from extragalactic AGN's. The optimal band for our purposes will be the band R6 (≈ 0.9 -1.3 keV). This band is the best in terms of instrumental response, background contamination and cluster vs AGN emission. The ROSAT maps have been *cleaned* from the most prominent point sources (sources above the threshold 0.02 cts/s in the R5+R6 band). However, we should note that for the above threshold, the survey source catalogue was incomplete and there are still some (very hard) point sources present in the maps of the diffuse X-ray background. We also have to note that during the point source subtraction process several *compact* clusters were removed from the data. This fact may introduce a systematic error in our conclusions which will be discussed later.

In order to maximise the extragalactic signal, we restrict our analysis to regions outside the galactic plane. In particular, we will consider only a *clean* portion of the sky above $b = 40^\circ$ and $70^\circ < \ell < 250^\circ$ which will also exclude the contribution from the north-galactic spur. This *optimal* area of the sky covers $\approx 9\%$ of the sky.

We also have to remove a few bright point sources in the ROSAT maps which were not originally removed. Some of these sources will produce a correlation signal if we do not remove them. One of these bright sources (MRK 0421) was already identified in a previous work as a source of correlation between ROSAT and COBE maps (Kneissl et al. 1997).

The power spectrum of $WMAP \otimes ROSAT$ (power spectrum of the product of the maps in real space) is shown in figure 1. At large scales (small multipoles) the product maps contains more power than at small scales (large l 's). This is mostly due to the smoothing process of WMAP maps (1°) which suppresses power at small scales. We should also mention that, contrary to what happens in the cross-power spectrum, the power spectrum of the product maps does

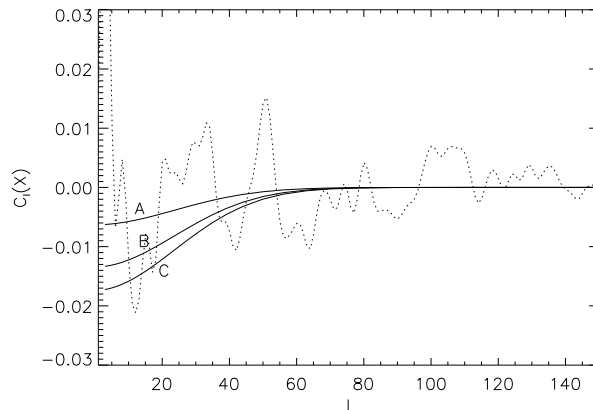


Fig. 2. Cross-power spectrum (dotted line) compared with the models $\sigma_8 = 0.8$ (A), $\sigma_8 = 0.9$ (B) and $\sigma_8 = 1.0$ (C).

not have to be 0 if there is no correlation between the maps. This fact makes more difficult the identification of a correlation between two maps. In order to identify possible correlations we have to rotate one of the maps. Then, if there is a spatial correlation between the maps, the power spectrum will be smaller after rotating one of the maps. When we do that for several rotation angles we observe that the power spectrum does not change. This means that there is not a significant correlation between the maps.

When we look at the cross-power spectrum, we do not observe any significant correlation either. The cross-power spectrum oscillates around 0 as expected for two maps which are not correlated. The cross-power spectrum is the k -ring average of the product of the Fourier modes of the two maps. If the maps are not correlated this average must be 0.

Although we do not detect any signal neither with the power spectrum of the product maps nor the cross-power spectrum, we can still use this fact to set some constraints on the model. In figures 1 and 2 we compare the measured power and cross-power with three different models where we change the parameter σ_8 (Ω_m is fixed to 0.3). This simple comparison tell us that models with low σ_8 are favoured by the observed lack of correlation between the two data sets. High values of σ_8 can be accommodated if the SZ effect is significantly contaminated by point sources (embedded in the clusters) so the net distortion in the CMB is smaller than if the cluster signal is just pure SZ effect (point sources contribute as positive signals while the SZ effect is negative at the frequencies considered in this work). High values of σ_8 can also be compatible with the data if the fraction of clusters removed in the point source subtraction process in ROSAT data contribute significantly to the power spectrum and cross-power spectrum. We have estimated this possible source in systematic error in the *worst-scenario* case in which all the clusters

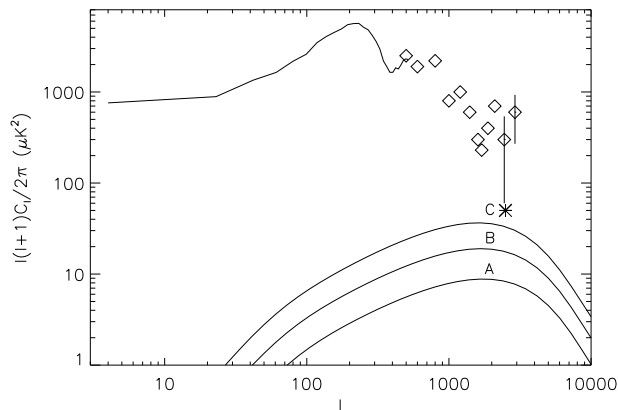


Fig. 3. Current estimates of the CMB power spectrum compared with predicted SZ effect power spectrum (R-J) for the previous models A,B, and C. The top solid line is a rebinning (10 bins) of the original WMAP CMB power spectrum. The symbols are current estimates by CBI and ACBAR (error bars have been omitted except in the last two points). The last three symbols at $\ell \approx 3000$ are the estimated power spectrum at high ℓ by CBI (top), ACBAR (middle) and the expected CMB power spectrum for a standard model (bottom star).

above the 0.02 cts/s point source removal threshold have been subtracted. In this case the theoretical power spectrum shown in figures 1 and 2 should be smaller by a factor ≈ 3 . Taking this reduction in power into account, models with $\sigma_8 = 0.9$ could be marginally consistent with the lack of correlation but models with $\sigma_8 = 1.0$ still seem difficult to reconcile.

3 conclusions

We do not find any significant correlation between WMAP and ROSAT. This lack of correlation can be due to contamination of the SZ effect by point sources, a significant reduction in the cluster signal due to erroneously subtracted clusters during the point source subtraction process in ROSAT data, the possibility that we live in a universe with a low normalisation of the power spectrum σ_8 or a combination of the previous factors.

We found that different assumptions about the model lead to different fits to the data. In particular, high values of σ_8 seem to be difficult to reconcile with the absence of significant correlation.

This absence of significant correlation could also be used to rule out the possibility that the excess in ACBAR and CBI is due to SZ effect. We illustrate this point in figure 3 where we compare the power spectrum of the SZ effect for the models A,B, and C with the recent estimate of the CMB power spectrum by WMAP (solid line) and with estimates from ACBAR (Kuo et al. 2003) and CBI (Mason et al. 2003).

From this plot we could conclude that the fact that we do not observe a correlation between WMAP and ROSAT implies that the SZ effect power spectrum should not contribute significantly to any of these experiments. Unfortunately, the quality of the data does not allow us to make such a severe affirmation. An updated version of this work made with the four year CMB data from WMAP and a new version of the soft X-ray diffuse background maps (with no cluster subtraction) could certainly help to answer this question.

4 Acknowledgements

This research has been supported by a Marie Curie Fellowship of the European Community programme *Improving the Human Research Potential and Socio-Economic knowledge* under contract number HPMF-CT-2000-00967.

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